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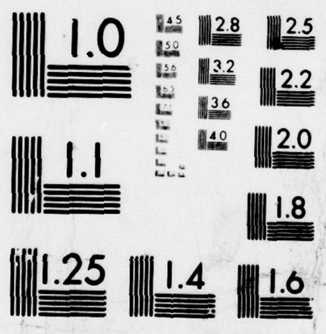

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PROTOTYPE LIQUID CRYSTAL RETICLE

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Culver City, California 90230

Contract DAAK70-78-C-0023
NVL Project 1E263710DK70-04

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Prepared for
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A productized liquid crystal reticle (LCR) was designed, fabricated and tested with 49 lines for elevation and 299 lines for azimuth. The prototype LCR incorporated a shock and vibration resistant mounting scheme with transparent thin film heater. This LCR was installed on a thermal nightsight using essentially the same volume as the existing fixed reticle. The LCR was operated on the thermal nightsight using a separate simple electronics controller with only one reticle line not functional.

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Results from this task demonstrated that a LCR, designed to withstand the armored vehicle environment, can be installed and operated with a thermal nightsight.

PREFACE AND ACKNOWLEDGEMENTS

Fabrication of a Prototype Liquid Crystal Reticle and installation onto a thermal nightsight was conducted by the Hughes Aircraft Company of Culver City, California from October 1978 through May 1979, under contract DAAK 70-78-C-0023 for the U. S. Army Night Vision and Electro-Optics Laboratory, Fort Belvoir, Virginia. This is the final report relating to that effort.

Mr. Clifton S. Fox served as the Contracting Officer's Representative for the program. Principal Hughes Laser Systems Division personnel were Mr. L. W. Hill, Program Manager, with Messrs. B. C. Gilbert and W. F. Stokes Project Engineers. Particularly valuable contributions were made by Mr. H. Lowen for mechanical design and Mr. C. Powell for electronics. Dr. P. Y. Hsieh and Mr. T. Ammons fabricated the reticle in the Technology Support Division. Consulting services were provided by Dr's J. D. Margerium and G. D. Myer of the Hughes Research Laboratories.

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SECTION I

INTRODUCTION AND SUMMARY

The liquid crystal reticle (LCR) is an electronically-operated digital moving reticle mounted directly into the optical train of a sight. The LCR has many important advantages over state-of-the-art servo-driven opto-mechanical projected reticle: These are

1. Digital design and simple computer interface
2. Much smaller size and weight
3. Stable boresight and excellent linearity
4. No moving parts and much better reliability
5. Lower aquisition and maintenance costs, both for the device itself and for the system of which it is a part
6. Improved light transmission as beamsplitters are eliminated.

In all, the LCR is a much more attractive device.

Several feasibility models of a LCR have been demonstrated successfully. Results from the previous NV&EOL contract proved that a LCR can be made to withstand the armored vehicle environment. The results of that contract are summarized below:

1. Demonstrated operation of a LCR from -40 to +125°F with the aid of a transparent thin film heater on the reticle itself
2. Resistance to 100g, 2 ms shock and 4g, 9 to 500 Hz vibration, while maintaining accurate boresight

Since these results were obtained, two new Hughes developments have occurred that greatly improve the LCR performance:

1. A new electronic driver scheme that improves flexibility and simplifies computer interface incorporated into the prototype LCR delivered to NV&EOL under this contract.
2. Development of a Hughes proprietary liquid crystal material that operates at +158°F.

The prototype LCR delivered under this contract was designed successfully to incorporate most of these technological developments. with 49 lines for elevation and 299 lines for azimuth. (Not enough new liquid crystal material was available to use in the delivered prototype reticle, so an older, similar material was used). Other developments that were demonstrated successfully are:

1. A productized liquid crystal reticle—only one reticle line, out of 348, was not functional This problem may have been caused by either the driver chip or the substrate.
2. Installation on the Magnavox TIRE thermal nightsight, using essentially the same volume as the existing fixed reticle
3. A new, Hughes-developed, electronic driver scheme with simple to operate electronic controller

The scope of this contract was increased on a best-effort basis to include edgelighting and enhancing the reticle image on a dark background. The results of this first attempt were partially successful and point to further investigations. A recommendation is presented in Section VI.

This technical report documents the prototype LCR from design and assembly to installation and operation with a thermal nightsight. This report is organized into four sections. Section I describes the mechanical design task. Section II describes the prototype LCR fabrication and testing. Section III describes the electronic controller built to operate the prototype LCR, while Section IV describes installation and operation of the prototype LCR with a Magnavox TIRE thermal nightsight.

SECTION II

MECHANICAL DESIGN TASK

2.1 AIMS AND OBJECTIVES

An optimized design for the prototype LCR and housing was required to interface with the Magnovox TIRE. The completed assembly was also designed to fit in essentially the same space as that of the fixed reticle.

2.2 MECHANICAL DESIGN

The LCR housing is composed of three sections:

1. A basic housing to support the LCR substrate assembly and the eyepiece
2. An adapter plate to provide sealing interfaces to the TIRE unit
3. A connector housing to terminate interconnection output wires.

The LCR housing was developed to retain the basic mounting hole patterns of the existing sight for attaching the eyepiece and adapting onto the TIRE unit. It provides the mounting features to accurately locate and retain the LCR substrate assembly to the optical axis of the sight.

Basic interface adjustments were required to the housing and the interface adapter plate to provide optical corrections because of the added glass path of the LCR substrate. These corrections were initially calculated but had to be trimmed at the time of installation.

Hughes initial proposal defined an electrical cable terminating internally from the LCR assembly into the TIRE sight. When the actual sight unit was inspected, this approach was abandoned because of the many new interface problems in coordinating changes to the existing sight. The basic unit was modified to adapt a sealed header housing to terminate the wiring connections externally. The internal plan, however, would be preferred on future development programs for reduced cost and improved unit appearance.

Techniques developed from the previous NV&EOL contract were used to fabricate the LCR substrate assembly. The integrated LCR assembly was structurally bonded to form a monolithic type unit proven capable of retaining alignment during high shock, vibration, and thermal exposures. The basic LCR substrate consists of two glass plates on which the reticle and interconnecting lines were deposited and etched. The plates were structurally bonded together with a thin adhesive film acting as a spacer and barrier around the central active liquid crystal region. After sealing this active area, a thin film heater was incorporated. Later, a number of stainless steel brackets and pads were accurately bonded in place to provide the interfaces necessary for mounting the completed LCR assembly into the unit housing with mounting connectors and covers. These stainless steel parts closely match the thermal characteristics of the glass substrate. This technique was used to avoid putting holes into the glass substrates that might cause stress propagating cracks.

After these bonding operations, the substrate chips are installed and interconnected. All the interconnections from the substrate are terminated to a printed circuit type elastomate connector (Ampliflex) and a wiring board and are then routed to an external connector housing. Two glass multi-terminal headers are bonded in place inside this connector housing. The assembly is wired and mounted onto the LCR housing, providing a sealed cable junction for the terminating electrical cable.

The base LCR substrate was designed to provide a compact configuration that could be integrated into the TIRE sight. Tradeoff studies were made to determine the best possible form factor of the substrate and the most efficient arrangement of the logic chips and connectors. The resulting design of the substrate was simple to fabricate. The thickness of the glass could be reduced from 0.25 to 0.125 inch, making an even more compact module; however, past tests and analyses were based on the thicker substrate, so there was no change at this time without additional backup data.

The etched logic pad clusters on the substrate were configured to permit the easy removal and replacement of defective electronic driver chips without damaging the interconnecting circuitry. This provision

proved helpful because some electronic drive chips were defective when the completed assembly was tested. Electronic driver chips were protected, after die attachment on the substrate by plastic covers.

Initially, plastic protective covers were designed to provide electronic driver chip protection by simple attachment to metal frames which were side bonded on the glass substrates. During this period, the scope of this contract was increased on a best-effort basis to include edge lighting and to enhance the reticle image on a dark background. Laboratory tests proved that the reticle image against dark background is enhanced by small light bulbs around the glass substrates. Since no space was available around the glass substrate periphery in the newly designed housing, each plastic cover for electronic driver chip protection was modified to include two small light bulbs. The covers and potted areas containing light bulbs are shown in Figure 1. The four light bulbs (wired in series) transmit light through a substrate edge. This method of edge lighting, although extremely compact, did not provide the degree of reticle image enhancement desired. Results are discussed in Section V. Additional image enhancement schemes are being considered.

2.3 CONCLUSIONS

A prototype LCR with housing has been successfully designed, fabricated and installed on the Magnavox TIRE thermal nightsight in the existing space provided for a fixed reticle. This reticle incorporates results of shock, vibration and thin film heater developments from the previous NV&EOL contract. Edge lighting to enhance the reticle image on a dark background was also included.

SECTION III

PROTOTYPE LIQUID CRYSTAL RETICLE TASK

3.1 AIMS AND OBJECTIVES

A working prototype model of a single-axis LCR which can be installed on the Magnavox TIRE thermal nightsight was designed, fabricated, assembled and tested. This reticle required approximately 300 lines in azimuth and 50 lines in elevation. The prototype LCR was also to incorporate both the thin film heater and the shock and vibration mounting scheme developed on the previous NV&EOL contract. In other respects, the reticle was to resemble the current Hughes configuration. Attempts were made to incorporate the latest technology available from other current programs, such as a new Hughes-developed electronic driver circuit.

3.2 DESIGN, FABRICATION, AND ASSEMBLY

A Hughes prototype LCR built for laser/daysight in 1977 used 1.2 mil wide lines with 0.532 mil spacing for a 1.732 mil center-to-center line spacing. This system used an objective lens with an effective focal length (EFL) of 8.66 inches. Therefore, to obtain a 0.2 angular mil resolution with 0.1 angular mil accuracy, the center-to-center line spacing was 1.732 mils. This same spacing was used for the prototype LCR, as accurate TIRE optical data were not available during layout design.

TIRE optical data were eventually received, and an estimate of mrad angular increment between lines was determined as follows. An Army standard eyepiece is used on the TIRE with an EFL of 1.33 inches. From the TIRE manual, it was assumed that the magnification is 8X in the narrow field-of-view; therefore, the objective lens has an EFL of 10.64 inches. It was also assumed that the EFL for the objective lens includes the IR optics. Therefore, using these two assumptions, the angular increment for each line was calculated at 0.163 mrads.

After the LCR housing was defined, the size and shape of both elevation and azimuth plates were determined. Both new elevation and azimuth plate layouts were roughly 50 percent smaller than previously manufactured plates. This reduction was realized with the use of a new electronic driving scheme. This scheme was developed as part of a Hughes IR&D program.

Layout for the elevation plate was straightforward. The elevation plate contained 49 lines (with boresight at line 24) and alphanumerics were the same as those used on an earlier Hughes prototype; four numerical digits, three indicators and four discrete messages. (It should be noted that future alphanumeric format possibilities are virtually unlimited). Three CMOS driver chips were designed to mount on the elevation plate to address reticle lines and alphanumerics, using eight input/output (I/O) control lines. Reliable electrical connection to the eight I/O control lines was made via an Ampliflex connector to a small printed wiring board. Two permanent concentric boresight circles were also designed into the elevation plate in case power is lost to the LCR. The overall size of the elevation plate, less covers, is 3.45 x 1.73 x 0.25 inches.

Layout space for the azimuth plate required more care and innovation. The azimuth plate contained 299 lines (with boresight at line 149) and the backplane for the alphanumerics. Ten CMOS driver chips were designed to mount on the azimuth plate to address reticle lines, again using eight I/O control lines. Most of the azimuth and elevation control lines are shared, which greatly reduces the total number of I/O control lines. The connector configuration is the same as for the elevation plate. The overall size of the azimuth plate, less covers, is 2.20 x 2.01 x 0.25 inches.

The overall LCR size is 3.45 x 2.01 x 0.50 inches, less covers, connectors, thin film heater and mounting feet. Three point shock and vibration mounting feet were designed to attach on the azimuth plate and not interfere with placement of the thin film heater. A thin film heater of approximately 1.35 x 1.30 inches was deposited over the LC cell; 22 ohms

per square indium tin oxide (ITO) was used. A Minco S1026, Ni-Fe ribbon thermocouple with self-stick adhesive was mounted on the azimuth plate in close proximity to the thin film heater.

Each layout was digitized on a Calma interactive graphics system This system allowed the operator and mechanical designer to interact for changes and error correction. A Gerber photo-plotter supplied with Kodak high resolution film was used to generate 10X photoplots for each layout.

Hughes selected the same vendor used in the past to produce the chrome masks for etching reticle plates. Three attempts were necessary to produce usable chrome masks from the 10X photoplots. The first attempt pointed out a deficiency in the exposure control mechanism on the Gerber photoplotter; this problem was corrected rapidly and new photoplots generated. A second attempt produced ragged, uneven lines and glass chips opposite the chrome emulsion. A third attempt produced usable chrome photo masks still with uneven and ragged lines, but without glass chips. These were the masks used for the prototype reticle.

Several sets of glass substrates were cut to shape and processed. Elevation plates had higher line yield, as expected, because of fewer lines. At first, none of the azimuth plates approached high line yield. Line yield was vastly improved on two sets of reticle plates using a pulsed xenon laser station to open line-to-line shorts. After the repair, visual inspection with a coaxial illumination microscope indicated that one set of plates had high line yield. At this point the two repaired azimuth plates were sent to Serriacin for deposition of the ITO thin film heater and were returned with 22 ohms per square of ITO.

Two LCRs were assembled using Ablefilm 539-II and LC filled with the DC material. No new liquid crystal material was available so the older material was used. (Both the sealant and LC material are the same used on the previous NV&EOL contract). LC fill holes were sealed with epoxy. A $60^{\circ}C$ temperature curing conductive epoxy was used for die attachment; aluminum wire was used for ultrasonic bonding. Aluminum wire provides

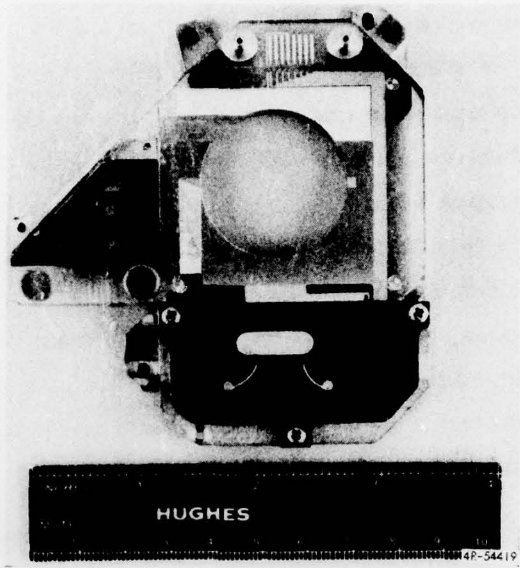
two important advantages: mechanically rigid interconnects, and repairability.

Connector posts were bonded on each reticle to attach the connectors for electrical testing. A mask error was found on the azimuth plates during initial electrical testing and was corrected by cutting the metallization and reconnecting with conductive epoxy. Reticle No. 1 was found to have 10 defective lines which stopped functioning approximately halfway across the LC cell. Microscopic examination indicated that these lines appeared to be cut by a fine scratch. Reticle No. 2 had one defective driver chip but no defective LCR lines in the cell area. This reticle was completed by bonding the metal frames on the edge of each plate. The defective chip was replaced and the reticle was retested. Only azimuth line 3 was not working. This reticle is shown in Figure 1.

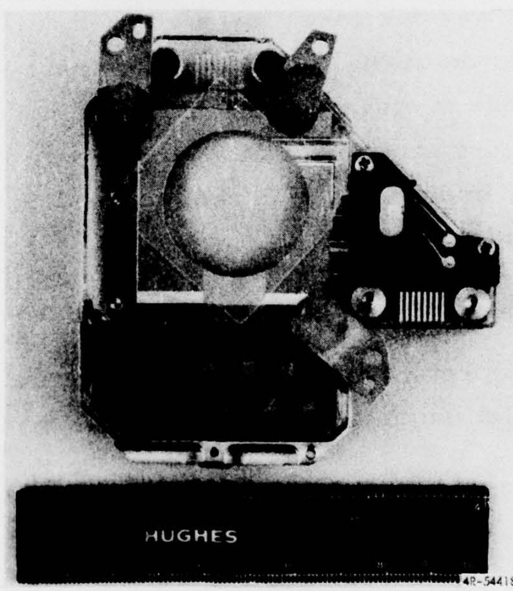
Two wires were attached to the thin film heater with conductive epoxy. The reticle was installed in the housing and the wiring completed (see Figure 2). The thermocouple is shown near the thin film heater.

3.3 CONCLUSIONS

A prototype LCR was designed, manufactured, tested and installed in a housing, suitable for mounting it onto the Magnavox TIRE thermal nightsight. Of the 49 lines in elevation and 299 lines in azimuth, both with 0.163 angular mrad spacing, only one line was not functional. This prototype reticle successfully integrated prior results for shock and vibration mounting plus a transparent thin film heater to allow operation from -40 to +125°F. In addition, this prototype LCR successfully incorporated a new Hughes developed electronic driver scheme that greatly reduces overall reticle size. In other respects, the reticle resembled the current Hughes configuration, such as alphanumeric display in the field-of-view.



a. Front



b. Rear

Figure 1. Prototype Liquid Crystal Reticle.

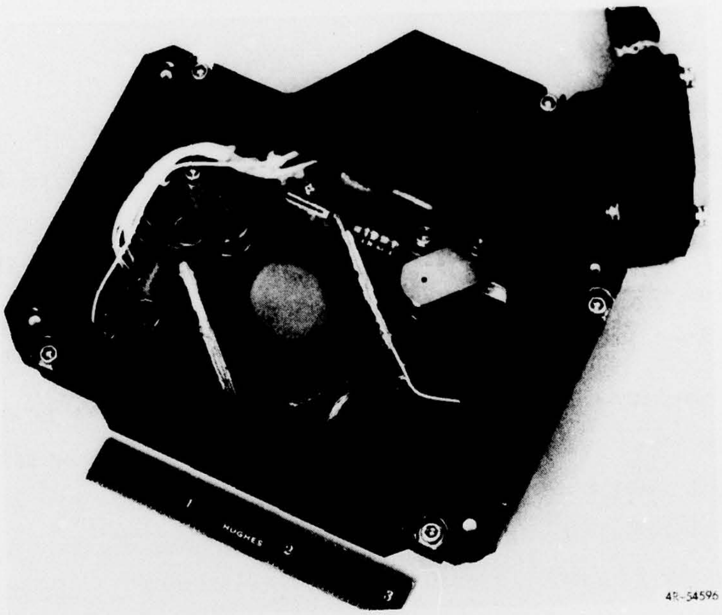


Figure 2. Completed Liquid Crystal Reticle in housing.

SECTION IV

ELECTRONIC CONTROLLER TASK

4.1 AIMS AND OBJECTIVES

An electronics unit was required to drive the prototype LCR and activate the transparent thin film heater to control the liquid crystal temperature. It was also important that the electronics be simple to operate.

4.2 RESULTS

A new Hughes-developed electronic circuit that individually addresses and drives reticle lines was incorporated into the prototype LCR. This electronic driving scheme was developed to simplify the electronic interface and add presentation format flexibility to a LCR. The prototype reticle includes independent selection of azimuth line, elevation line, and alphanumerics, plus a simple electronic driver chip self-test feature.

A stand-alone multifunction electronic controller based on a working Hughes design was modified, packaged and tested to drive the prototype LCR. This electronic controller was built for keyboard entry of command and data; hence, no provisions were made for alternate digital inputs. Although the main purpose of the electronic controller was to demonstrate the prototype LCR, two additional functions were also provided; a test mode and a diagnostic mode. The test mode was used during LCR assembly to determine defective driver chips and nonworking lines. This function was particularly important as semiconductor manufacturers did not guarantee 100 percent yield on chip-only deliveries. The diagnostic mode was intended to detect and indicate functional failures during LCR operation, such as data fail, power fail, backplane fail and heater fail.

An Intel single chip reprogrammable microprocessor was selected and used to provide the functions necessary to realize the controller. This microprocessor was programmed to scan the keyboards for command and data, monitor power supply functions, drive the LCR, drive status indicators,

control the heater, and perform maintenance functions such as a command display, data display, and a self test feature. An ability to change or modify electronic functions in software without hardware changes is truly unique. Characteristics of the electronic controller are summarized below:

1. Keyboard entry of command and data
2. Displays for command and data entered
3. Status indicators
4. Independent data entry of azimuth, elevation, alphanumerics, and heater control
5. Fast (10 lines/step) and slow (1 line/step) auto-step of reticle lines (up, down, left, right)
6. Selectable internal or external power source
7. 18-30 volt external input with Transorb protection (power converter needed for raw +24 volt from armored vehicles)
8. 22 volt battery for internal power
9. Brightness control for edge lighting

Figure 3 shows the electronic controller to drive the prototype LCR. The electronics drove an LCR the first time without any problems.

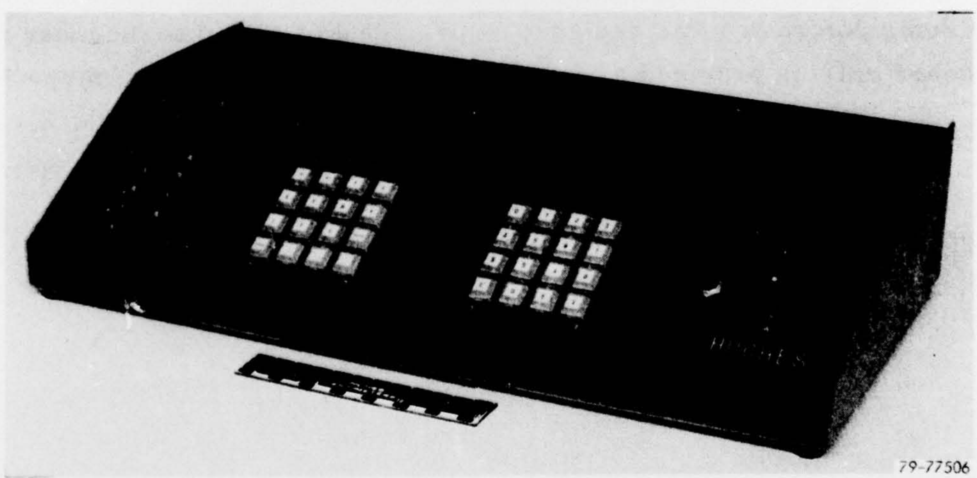


Figure 3. Electronic Controller

Soon after testing of the electronic controller, the microprocessor was programmed to bypass defective azimuth line 3. Depending on the last input of the auto-step azimuth function (that is, left or right) the microprocessor adds or subtracts one line. Thus, when azimuth line 3 is selected, either azimuth line 2 or 4 is actually used.

Since the prototype LCR and electronic controller were intended for demonstration, no attempt was made to miniaturize the electronic controller. Electronics layout was patterned after the working microprocessor breadboard. Liberal space was allowed for a DC-to-DC converter, +22 volt battery, wire wrap components, connectors and cables. Costs were minimized using commercially available components. It has been estimated that a LCR printed wiring board interface (including electronics) to a digital computer would be no larger than 3 inches square.

4.3 CONCLUSIONS

A multifunction electronic controller based on a working Hughes design was modified, packaged and tested to demonstrate the prototype LCR with unique ability to change or modify electronic functions in software without changing the hardware. In addition to demonstrating the LCR, the electronic controller was designed to provide status and to diagnose faults. Keyboard entries provided a simple method to control the prototype LCR.

SECTION V

PROTOTYPE LIQUID CRYSTAL RETICLE INSTALLATION

5.1 AIMS AND OBJECTIVES

The completed prototype LCR in housing was to be installed and operated with the Magnavox TIRE. It was also important that the reticle not interfere with mechanical or electrical operation of the Magnavox TIRE.

5.2 RESULTS

The fixed reticle with housing removed from the TIRE and the LCR with housing and electrical cable before installation are shown in Figure 4. Overall sizes between the two reticles were comparable. The TIRE eyepiece mounted on the LCR housing before installation on the TIRE is shown in Figure 5. The LCR housing, electrical cable, and eyepiece mounted on the TIRE are shown in Figure 6. The prototype LCR did not interfere with TIRE operation; the TIRE controls are clearly visible in the photograph.

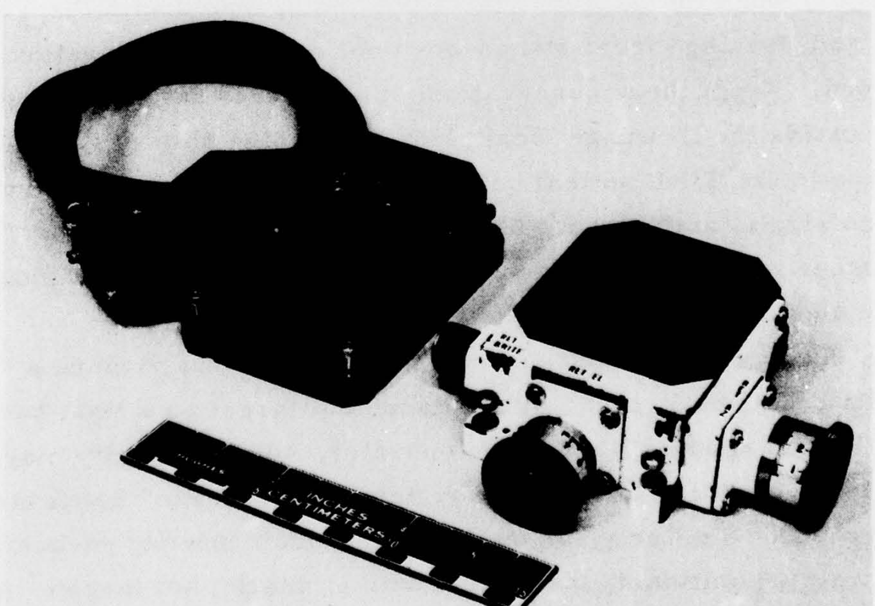


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Figure 4. Comparison of fixed reticle and liquid crystal reticle

Figure 5. TIRE eyepiece mounted on LCR housing

Initially when the LCR was installed and operated with the TIRE, the reticle and IR image focal planes were not coincident. Parallax was also observed. From these observations, it appeared that the reticle focal plane was outside the IR image focal plane. By using shims, the LCR was moved closer to the TIRE so that both image focal planes were coincident and parallax was significantly reduced. Shims were removed, and the TIRE mounting flange was machined accordingly. Both IR and reticle images were observed to be coincident with virtually no parallax.

The TIRE, as with most thermal nightsights, can produce a "white" hot target on a dark background or a "black" hot target on a light background. Since an LCR line appears black to an operator, some difficulty may be momentarily encountered locating the reticle with a "white" hot target and black background. Similarly, an operator may momentarily encounter difficulty accurately positioning the reticle onto a "black" hot target. Although not part of this contract, NV&EOL requested on a best effort basis that edge

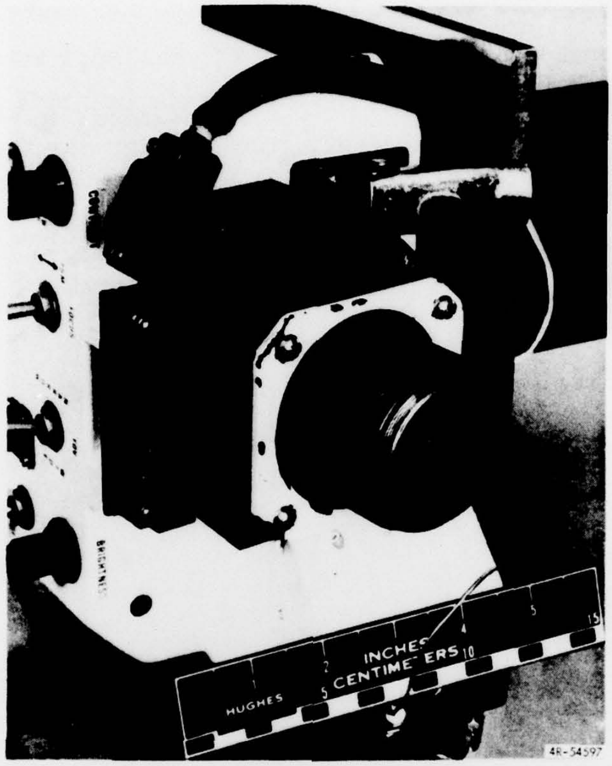

Figure 6. LCR housing, electrical cable, and eyepiece mounted on Magnavox TIRE.

lighting be incorporated to enhance the LCR image. The goal was to produce white reticle lines regardless of image polarity. Edgelighting proved marginally successful. Alphanumerics, even though distinguishable, were observed almost out of the eyepiece field-of-view (correctable by LCR layout changes). Thus, simultaneous viewing of the IR image and alphanumerics was difficult. In addition, insufficient illumination from the edge lights did not appreciably enhance the reticle image. Hughes has studied this problem further and is currently pursuing a solution.

A complete test of the LCR installed on a working TIRE was performed with the electronic controller. Operation of the controller proved simple, and no problems were encountered.

5.3 CONCLUSIONS

A prototype LCR was successfully installed and tested on the TIRE using the electronic controller. The mounting flange was adjusted so that both the IR image and reticle focal planes were coincident. Although edge lighting was not part of this contract, the concept was tested and implemented with some success. Operation of the prototype LCR did not interfere with mechanical or electrical operation of the Magnavox TIRE.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The delivered prototype Liquid Crystal Reticle, with 49 lines for elevation and 299 lines for azimuth has successfully demonstrated:

1. A transparent thin film heater that allows operation from -40 to +125°F
2. Shock and vibration mounting scheme for armored vehicle environments
3. A new Hughes developed electronic driver scheme with simple electronic controller
4. Installation on the TIRE thermal nighsight using essentially the same volume as the existing fixed reticle
5. Operation with the TIRE thermal nightsight with only one reticle line not functional.

The successful completion of this contract proves that a LCR, designed to withstand the armored vehicle environment, can be installed and operated with a TIRE thermal nightsight.

6.2 RECOMMENDATIONS

It is recommended that additional tasks be funded for the LCR to prove reliability and operational feasibility. Specifically, the following tasks are important:

1. Shock, vibration and temperature tests
2. Field tests in an armored vehicle with simple computer interface to prove operational feasibility
3. Further investigations of edge lighting.

It is recommended that an advanced development model be procured to demonstrate improved operational capability of an armored vehicle with a thermal nightsight. Finally, it is believed that the successful completion of this and concurrent efforts bring the concept of the liquid crystal reticle to the point where full-scale engineering development should be pursued.

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